The KASKA project – a Japanese medium-baseline reactor-neutrino oscillation experiment to measure the mixing angle θ_{13} –

Masahiro Kuze[a] (for the KASKA Collaboration*)

[a]Department of Physics, Tokyo Institute of Technology, Tokyo, 152-8551 Japan

A new reactor-neutrino oscillation experiment, KASKA, is proposed to measure the unknown neutrino-mixing angle θ_{13} using the world's most powerful Kashiwazaki-Kariwa nuclear power station. It will measure a very small deficit of reactor-neutrino flux using three identical detectors, two placed just close to the sources and one at a distance of about 1.8km. Its conceptual design and physics reach are discussed.

1. Introduction

The investigation of the mixing phenomena of the leptonic sector will be a major theme of particle physics in next few decades, as has been that of the quark mixing in the past. While two neutrino-mixing angles, θ_{12} and θ_{23}, have been measured to be fairly large [1,2,3,4], only upper limits have been obtained for the remaining angle θ_{13}. The best limit is $\sin^2 2\theta_{13} < 0.2$ for $\Delta m^2 = 2.0 \times 10^{-3}$ eV^2 from CHOOZ [5], and this smallness in contrast to the other angles is a mystery that challenges in building up a theory to explain the origin of the mixing. Not only the measurement of the angle itself is of high scientific interest, but also knowing the range of this parameter is a crucial input in planning for future very-long-baseline oscillation experiments to detect the leptonic CP-violating phase δ_{CP}, using very intense beams of neutrinos (and anti-neutrinos) from Superbeam facilities or Neutrino Factories.

It has been shown [6], also nicely in the plenary session of this workshop [7], that the detection (or setting new upper limit) of θ_{13} by $\bar{\nu_e}$ disappearance experiments with reactor neutrinos gives complementary information to that from the planned $\nu_\mu \to \nu_e$ appearance experiments with accelerator neutrino beams. Therefore, having both kinds of experiments, preferably concurrently, would be useful in the exploration of the mixing phenomena in the lepton sector.

The KASKA experiment will try to achieve the mission using reactor neutrinos from KAShiwazaki-KAriwa nuclear power station in Niigata, Japan. Its conceptual detector design, background and systematic-uncertainty consideration and physics reach will be discussed in the following.

*The KASKA group institutes at the time of the workshop were: KEK, Kobe Univ., Niigata Univ., Rikkyo Univ., Tohoku Univ., Tokyo Met. Univ. and Tokyo Tech.

2. The experiment

Kashiwazaki-Kariwa nuclear power station, owned and operated by Tokyo Electric Power Company, is the biggest source of reactor neutrinos in the world, with a power of 23.4 GWth. The station has seven reactors, which are clustered into four and three. The two clusters are separated by about 1.5 km in distance. The purpose of the KASKA experiment is to detect a small deficit of anti-neutrinos due to θ_{13} mixing:

$$\boldsymbol{P_{\bar{\nu}_e \to \bar{\nu}_e} = 1 - \sin^2 2\theta_{13} \sin^2 \frac{\Delta m^2_{13} L}{4 E_\nu} + \mathcal{O}(10^{-3}).} \quad (1)$$

Note that the value of Δm^2_{13} is very close to Δm^2_{23} measured by SK and K2K, as $\Delta m^2_{23} >> \Delta m^2_{12}$. With the neutrino energy considered (the detected neutrino energy peaks at 4 MeV), the oscillation maximum occurs at 1-2 km, and other effects (last term in Eq. 1) become negligible. Therefore, the experiment is a pure θ_{13} measurement and detects a small deficit due to θ_{13} and Δm^2_{13}, while the KamLAND experiment mea-

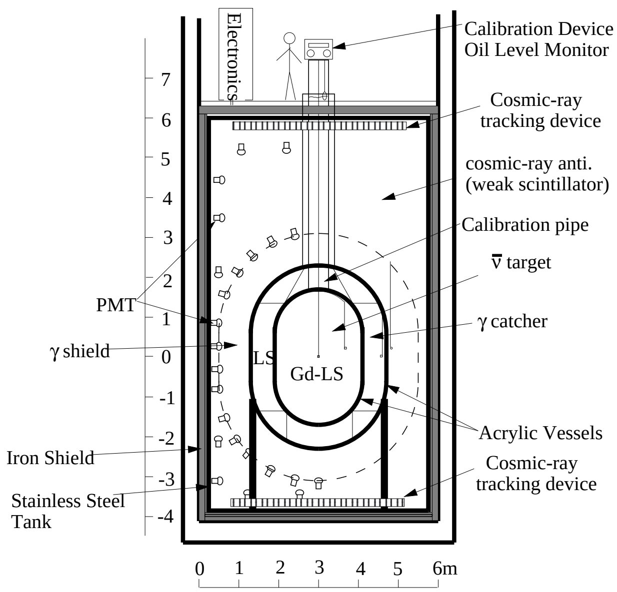

Figure 1. Schematic view of the KASKA detector.

sured a large deficit due to θ_{12} and Δm^2_{12} at a distance of about 180 km. In order to minimize the systematic uncertainties related to the absolute neutrino-flux estimation and absolute detection efficiency, it is planned to have multiple detectors, ones close to the source (near detectors) and the other close to the oscillation maximum (far detector). KASKA will have two near detectors for the two reactor clusters, each at a distance of approximately 400 m. The location of the far detector will be at about 1.8 km from both clusters, corresponding to the Δm^2_{23} value measured at SK and K2K.

Figure 1 shows the schematic view of the planned detector. It consists of the central target region and a few buffer and veto layers surrounding it. The neutrino target is 8 tons of liquid scintillator (LS) contained in an acrylic vessel. The LS is loaded with 0.1% of Gadolinium (Gd). The detection is via inverse-β reaction, $\bar{\nu}_e + p \rightarrow e^+ + n$, which produces a prompt signal due to the positron energy loss and its annihilation with an electron. As the recoil energy to the nucleon is very small, it gives a measurement of the incoming neutrino energy. Then the neutron is captured by Gd, which emits several γ-rays whose total energy amounts to 8 MeV. This gives a delayed signal, and taking a coincidence of the two signals in time sequence (the typical capture time is 30 μs) greatly reduces the background.

The target region is surrounded by the γ-catcher region, which is a 60-cm thick layer of LS without Gd loading, but with the same light output as the target LS. It detects γ rays that escaped from the target region, thus improving the energy reconstruction of the prompt and delayed signals.

Out of the γ catcher is the buffer region, a 90-cm layer of non-scintillating paraffin oil. This works as a shield against background γ and β rays from radioactive elements contained in the photomultiplier (PMT) glasses. The PMTs are attached at the outer surface of this region.

The outermost layer is the cosmic-veto region, a layer of LS with weak light output. This layer will be viewed by PMTs attached to the outermost part of the detector. It detects the cosmic muons entering the detector, giving a veto signal against background events associated with them.

In addition, there will be cosmic-ray tracking devices at the top and bottom of the detector. They will reconstruct the passage of the cosmic rays and will be used to estimate the background coming from muon spallation products.

In order to reduce the cosmic-induced background to a very low level, the detectors will be located in underground vertical shafts. The near detectors will be placed at a depth of about 70 m. The shaft for the far detector will be about 200 m deep, due to the smaller signal event rate. The expected cosmic-muon rates for the entire detector volume are roughly 100 Hz for the near detectors and 10 Hz for the far detector.

Following sources of background are considered:

- Accidental coincidence of e^+-like singles rate and neutron-like singles rate.
- Fast neutrons, mimicking a prompt signal (by recoiling a proton, for example) and

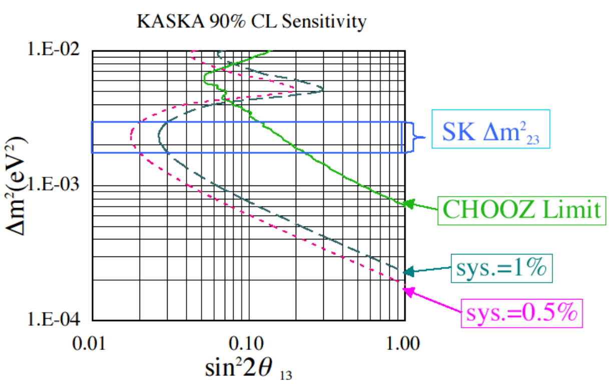

Figure 2. KASKA 90 % C.L. sensitivity after three years of running. The Δm^2_{23} region allowed by Super-Kamiokande [1] at 90 % C.L. is also indicated.

then captured, thus producing a correlated background.

- Long-lived spallation products, such as ^{9}Li or ^{8}He, induced by cosmic ray. Their decay involves β and neutron emissions, thus constituting a correlated background.

With enough shaft depth and shielding, it is possible to keep the background at the level of 1% of the signal, with an uncertainty of 0.3% or less.

With a running period of three years, the far detector will collect about 30,000 neutrino events, i.e. with a statistical error of 0.6%. During this period, the near detectors will collect 300,000 events each, providing also inputs for reactor science using the very precise neutrino β-spectrum. The main source of systematic uncertainty comes from the relative acceptance difference between the near and far detectors, originating, for instance, from the target volume. The analysis of the systematic sources can be found elsewhere [8]. It is possible to control the systematic uncertainty well below 1%. The uncertainty related to the absolute neutrino-flux estimation, which was fairly large in the earlier-generation reactor experiments, becomes negligible thanks to the multi-detector configuration.

Figure 2 shows the expected sensitivity [8] on $\sin^2 2\theta_{13}$ as a function of Δm^2, which improves on CHOOZ limits by one order of magnitude.

3. Status and prospects

The collaboration currently consists of seven Japanese institutes, and is growing. Two-year R&D funding was approved and has started from FY 2004. The R&D includes 1) boring study of geologies at the location of one of the near detectors, followed by in-situ background measurements (cosmic rates and γ backgrounds) at the bottom of the 70 m bore shaft, 2) building of a prototype detector (1.2-m diameter sphere) to study the energy-reconstruction systematics, and 3) development of readout electronics. With more institutes joining, further tests and developments are envisaged. The negotiations with the electric company and authorities have been progressing successfully. With an appropriate funding profile, the earliest schedule could be to start detector and shaft constructions in 2006 and to start data-taking in 2008.

REFERENCES

1. Super-Kamiokande Collaboration, Phys. Rev. Lett. 81, 1562 (1998); Phys. Rev. Lett. 85, 3999 (2000), Phys. Rev. Lett. 93, 101801 (2004).
2. SNO Collaboration, Phys. Rev. Lett. 89, 011301 (2002).
3. K2K Collaboration, Phys. Rev. Lett. 90, 041801 (2003).
4. KamLAND Collaboration, Phys. Rev. Lett. 90, 021802 (2003).
5. CHOOZ Collaboration, Eur. Phys. J. C27, 331(2003).
6. H. Minakata, H. Sugiyama, O. Yasuda, K. Inoue and F. Suekane, Phys. Rev. D68, 033017 (2003), hep-ph/0211111.
   Erratum, ibid. D70 (2004) 059901.
7. T. Lasserre, plenary contribution in these proceedings.
8. F. Suekane, Proceedings for NOON04, hep-ex/0407016.